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Short communication

Failure analysis of the impellers of coke plant

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ABSTRACT

Premature failure of the impeller blade of coke plant has been investigated. The component functioned during the CGC gas intake cycle. The component rotates at 1480 rpm with a volumetric flow of 720 m^3/min of flue gas with temperature about 200–300 °C. The failed component reveals exposed surface of a crack that extended slightly beyond the assembly weld. From macro-structural observation under-filled region in welding is observed which is detrimental because it acts as a stress concentration site. The microstructure from the weld zone showed severe intergranular corrosion degradation. Micro cracks and cracks have been observed at several locations, mostly originating from the weld zone. From the EDS analysis of the failed sample it is observed that there is a deposition of Cr along the grain boundary. From the mode of failure it indicates that probable reason for the premature failure is due to sensitization of the component. In this case, the precipitation of chromium carbides may be occurred during welding operation when the heat affected zone (HAZ) experiences a particular temperature range (550–850 °C). From the microstructure it is observed that the welding operation was not proper and there is every chance that there is heat generation in around sensitization range leading to precipitation of chromium carbides consumed the alloying element – chromium from a narrow band along the grain boundary and this makes the zone anodic to the unaffected grains. The chromium depleted zone becomes the preferential path for corrosion attack or crack propagation if under tensile stress. Thus it leads to premature failure of the component during service.

1. Introduction

Centrifugal pumps are turbo machines used for transporting air or gas by raising a specified volume of the flow to a specified pressure level. The basic centrifugal pump components are: the casing, the bearing housing, the pump shaft and the impeller. As the impeller rotates, the gas is accelerated by the rotating element within the confined space created by the volume of the compressor's casing. The gas is compressed as more gas is forced into the volute by the impeller blades. The pressure of the gas increases as it is pushed through the reduced free space within the volute. In these studies premature failure investigation of impeller blade was carried out. The component functioned during the CGC gas intake cycle. The component rotates at 1480 rpm with a volumetric flow of 720 m^3/min of flue gas with temperature about 200–300 °C. The expected life of the component is 5 years while the component failed within 3 years of its service (Fig. 1).

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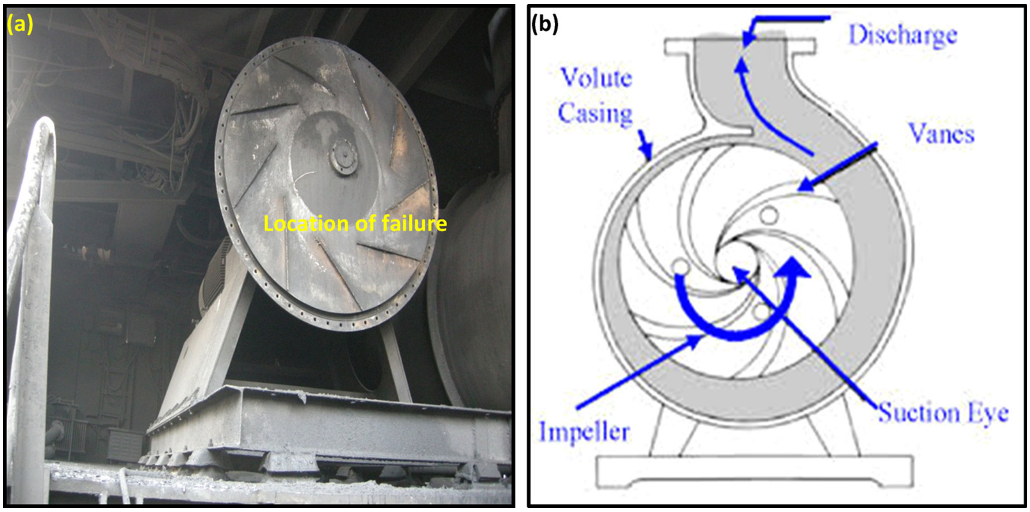

Fig. 1. (a) The assembly site of the failed impeller; (b) schematic drawing of the impeller.

2. Plant visit and visual observation:

Plant Visit was conducted to understand the problem. During plant visit it has been observed that after premature failure of the component several areas were detected on the blades and at the attachment zone of the blades and the hub where weld-repair work on the cast was performed. A triangular piece of the first centrifugal blower impeller blade was submitted for metallurgical analysis of the cause of cracking. The piece had been extracted from the rest of the blade, as referenced Fig. 2a. It contained an exposed surface of a crack that extended slightly beyond the assembly weld from the leading edge

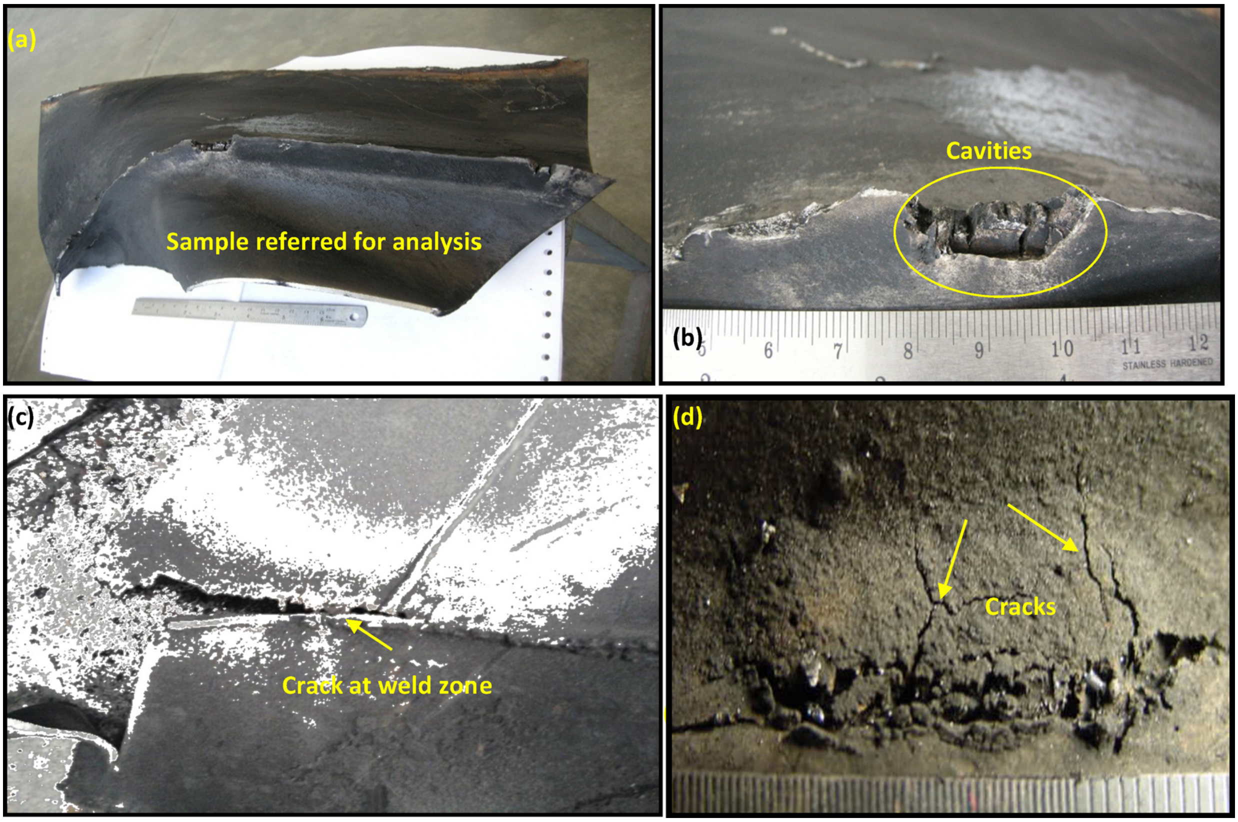

Fig. 2. (a) Full view of sample referred for analysis; (b–d) cracks at various location of the component.

Table 1
Chemical analysis (wt.%).

Sample name	C	Mn	S	P	Si	V	Al	Ti	Cr	Mo	Cu	Ni	Nb
Impeller	0.056	1.57	0.002	0.016	0.522	0.085	0.007	0.018	18.6	2.42	0.088	13	0.014
316L	0.03 max	2.00 max	0.030 max	0.045 max	1.0 max	–	–	–	16.0–18.0	2.0–3.0	–	10.0–14.0	–

where cavities were observed (Fig. 2c and d). A crack which encompassed the leading edge and extended down one side (pressure side) of the blade sample was observed. Corrosion pitting was noted along the leading edge and along the crack path in the blade edge, the suspected crack initiation area.

2.1. Chemical analysis

The chemical composition of the impeller material was determined and the results are given in Table 1 along with the specified chemical composition. The analysis revealed that the impeller material is an austenitic stainless steel. The actual chemical composition shows carbon somewhat on the high side. However, the small difference in chemical composition is unlikely to influence the performance of the impellers to a significant extent.

Small sample containing fracture surface were cut from the cracked blade and were mounted with resin, ground and polished using standard metallographic technique as shown in Fig. 3a. Macro and microstructural characterization was carried out using optical microscope (Leica, model: DMRX, Germany). Macro dual image of metallographic sample shows that under fill region is present in welded region. Closer view of sample as shown in Fig. 3b shows signature of corrosion adjacent to the weld region of the impeller blade.

2.2. Microstructure

Un-etched microstructure of the impeller reveals cracks with branching (Fig. 4a). The polished samples were etched using aqua regia for microstructural study. Under-filled region in welding is observed from Fig. 4b. Under filled region in welding is detrimental because it acts as a stress concentration site. The microstructure from the weld zone showed several abnormalities. Severe intergranular corrosion (IGC) degradation has been observed in the microstructure (Fig. 4c). Micro cracks and cracks have been observed at several locations, mostly originating from the weld zone. However the microstructure from the un-effected region of the sample shows an austenitic matrix without any irregularity (Fig. 4d).

3. SEM-EDS analysis

Energy dispersive X-ray spectroscopy (EDS) was carried out extensively using high magnification scanning electron microscope (SEM) to find out the composition of the precipitates at the grain boundaries as well as at certain spots within matrix. The results are tabulated in Table 2. From the analysis it is indicating that precipitation of chromium was observed along the grain boundary.

3.1. Hardness

Hardness of the impeller was measured on Vickers's scale using 30 kg weight by means of the same sample that was used for metallographic study. The measured hardness value of 160–170 HV was acceptable for application.

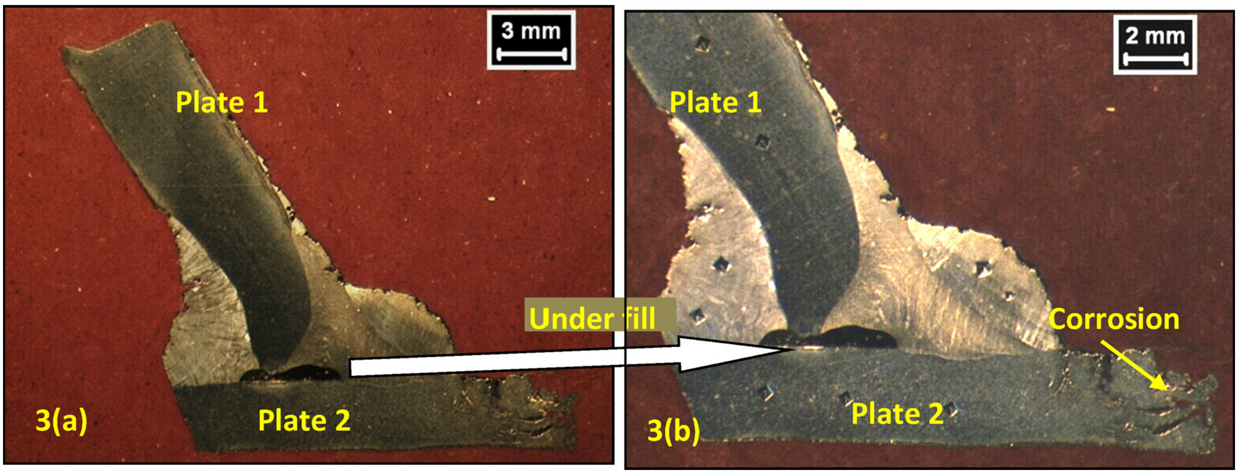

Fig. 3. (a and b) Macro dual image of impeller.

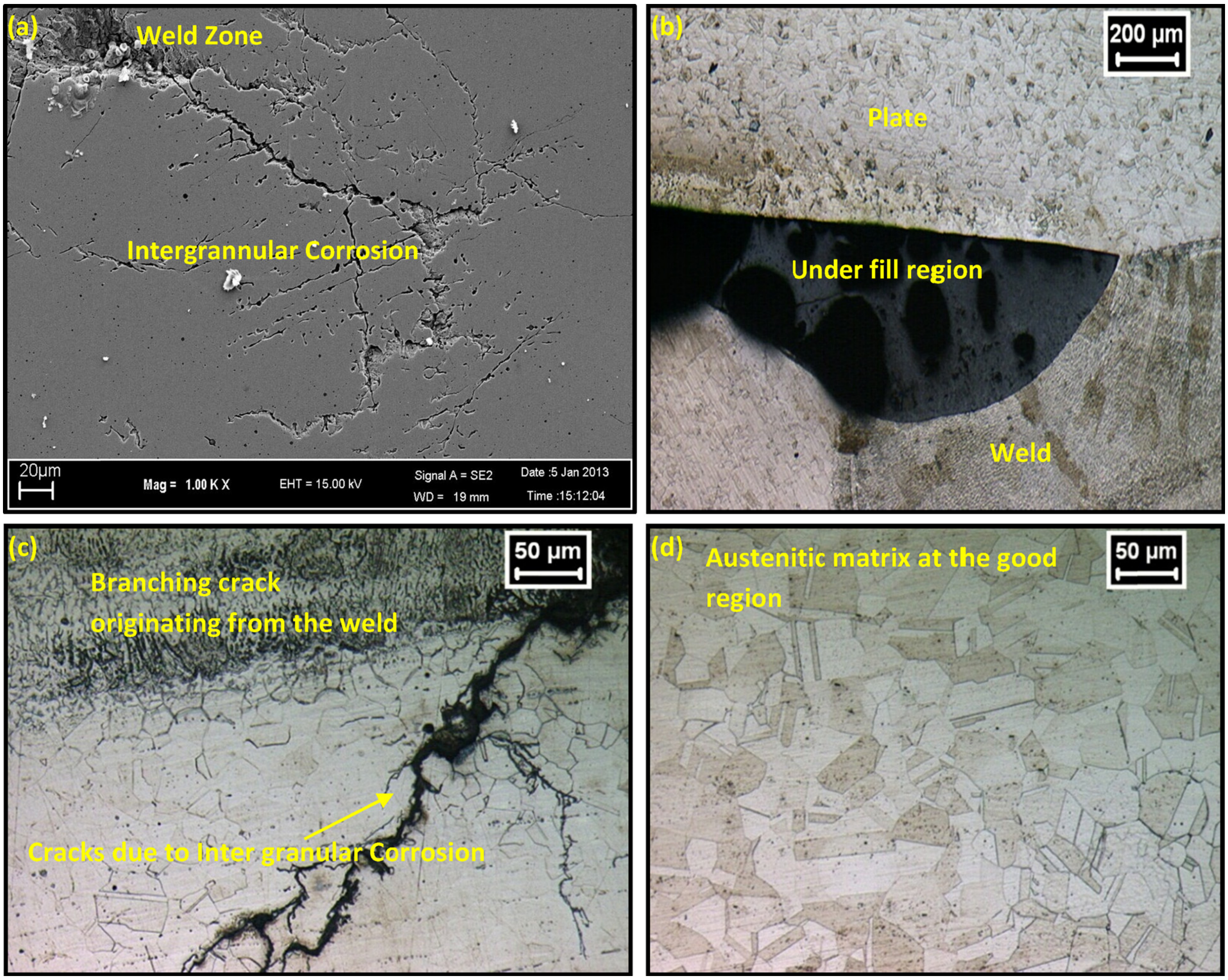

Fig. 4. (a) Un-etched microstructure of the impeller and (b) under-filled region in welding is observed. (c) Microstructure from damaged portion of the sample. (d) Microstructure from good region of the sample.

Table 2
EDS Analysis (wt.%).

Spectrum	C	O	Al	Si	S	Cl	Ti	Cr	Mn	Fe	Ni	Total
1	3.63	41.46		2.61	2.24	0.33		35.71		11.50	2.52	100.00
2	4.12	8.93		0.75	0.92	0.12		19.31		56.86	8.99	100.00
3	8.48	27.31		1.06	1.94			32.38		24.67	4.16	100.00
4	2.40			0.74	0.30			17.60	1.13	67.45	10.38	100.00
5	69.38	11.51		0.24				4.38		12.83	1.65	100.00
6	2.03	39.66	0.30	21.06	1.66		1.30	5.63	22.56	5.80		100.00
Max.	69.38	41.46	0.30	21.06	2.24	0.33	1.30	35.71	22.56	67.45	10.38	
Min.	2.03	8.93	0.30	0.24	0.30	0.12	1.30	4.38	1.13	5.80	1.65	

4. Discussions

Premature failure of the impeller blade of coke plant has been investigated. The component functioned during the CGC gas intake cycle. The component rotates at 1480 rpm with a volumetric flow of 720 m^3/min of flue gas with temperature about 200–300 °C. Visual observation of the failed component reveals exposed surface of a crack that extended slightly beyond the assembly weld from the leading edge where cavities were also observed. From macro-structural observation under-filled region in welding is observed. Under filled region in welding is detrimental because it acts as a stress concentration site. The microstructure from the weld zone showed several abnormalities. Severe intergranular corrosion degradation has been observed in the microstructure. Micro cracks and cracks have been observed at several locations, mostly originating from the weld zone. From the EDS analysis of the failed sample it is observed that there is a deposition of Cr along the grain boundary. From the mode of failure it indicates that probable reason for the premature failure is due to sensitization of the component and which later on accelerated by sulphide stress corrosion cracking. The sensitization phenomenon occurs when stainless steel is cooled slowly from high temperatures or reheated to the critical temperature range of 550–870 °C [1–4]. Therefore, at some point in during the welding process (during the heating and cooling cycle), some parts of the component underwent temperature excursions within the sensitization range. In this condition, the carbon content exceeded the solubility limit of austenite phase, causing carbon atoms bond with the Cr atoms, forming a continuous network of Cr carbides along the grain boundaries. Since carbon atoms diffuse faster than chromium atoms, a Cr-depleted region develops in the austenite matrix adjacent to these Cr-rich precipitates, providing a continuous path of lower corrosion resistance along the grain boundaries for the propagation of IGC or IGSCC [5–7]. A high carbon content is also a critical point for the occurrence of sensitization. As can be seen in Table 1, the plates used in the construction of the impeller have a carbon content of 0.056%, which is almost twofold higher than the maximum allowable limit of 0.03% for a weld able grade. In this case, the precipitation of chromium carbides occurred by the welding operation when the heat affected zone (HAZ) experiences a particular temperature range (550–850 °C). From the microstructure it is observed that the welding operation was not proper and there is every chance that there is heat generation in around sensitization range leading to precipitation of chromium carbides consumed the alloying element – chromium from a narrow band along the grain boundary and this makes the zone anodic to the unaffected grains. The chromium depleted zone becomes the preferential path for corrosion attack or crack propagation if under tensile stress. Thus it leads to premature failure of the component during service.

5. Conclusion

The impeller of the coke plant failed due to material degradation caused by intergranular corrosion (IGC) due to sensitization.

6. Recommendation

Use of low carbon varieties, i.e. 304L or 304LN austenitic stainless steels which are resistant to sensitization is recommended for use in welded components exposed to prolonged service to avoid similar failures in future.

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